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ASTROPHYSICAL PHENOMENA AND RADIOCARBON

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SUMMARY

This work expands the basic propositions of the problem "Astrophysical Phenomena and Radiocarbon" presented by the authors in article [1].

I. INTRODUCTION

The intensity of physical experiments in outer space has sharply increased with the development of satellite technology. Investigations in space are of both purely scientific and practical interest. Naturally, this distinction is purely conventional, since without knowing the regularities of processes occuring in space (the scientific side of the problem) it is impossible to carry out space flights with astronauts, (i.e. manned space flights). On the other hand, a detailed investigation of various phenomena necessitates the participation of astronauts in the experiments. Therefore, both sides of the problems are interconnected and complement each other.

It is well known that the forecasting of solar conditions which in a major degree determine the conditions in the Earth's atmosphere and near-terrestrial space is of utmost importance from the standpoint of the safety of flights. The knowledge of the characteristics of various processes in the Sun can make it possible to forecast solar conditions. To this end, it is necessary to study in detail the energy spectrum and the intensity of both the corpuscular and the electromagnetic radiation of the Sun, and to determine the time dependence of the processes.

The existing methods of investigation consist in registering the events, whose signals are received during the experiment. In the case of the Sun, the investigated processes are virtually occurring at a given moment of time. On the other hand, investigations of the time dependence of processes require the availability of data covering a sufficiently large time interval. Naturally, the length of this interval depends on the phenomenon being studied. If, for instance, we are concerned with the 80-year cycle of solar activity, the duration of the time interval has to be of several hundred years, and so forth. Knowledge of past solar conditions for a long time interval would make it possible to forecast future solar conditions. In this connection, it is appropriate to develop methods for studying the past conditions of the Sun, of the Earth's atmosphere and of the near-terrestrial space. The necessity of finding "eye-witnesses" of the past does not arise solely in connection with studies of the temporal course of the state of the Sun. Up to now, the outburst mechanism of supernovae which, according to our present notions, are the source of cosmic rays, still remains unclear. The difficulty of investigating supernovae outbursts is due to a large degree to the fact that the sensitivity of up-to-date methods of radiation recording (gamma-and X-rays, neutrino) do not permit the study of star flares in other galaxies. Whether a flare is to occur in the near future in our Galaxy is unknown. What is reliably known is that during the last millenium at least three supernova outbursts took place in our Galaxy. Naturally, here we are confronted with the problem of whether these outbursts have left a trace in the solar system that could make it possible to determine their characteristics.

In 1965 the authors of this article drew attention [1] to the possibility of studying various astrophysical phenomena by way of determination of the radiocarbon content in specimens of a known age.

The present work is devoted to the development and a more detailed investigation of the basic concepts contained in the aforementioned article.

II. C^{14} DISTRIBUTION IN VARIOUS RESERVOIRS

The opinion on the origin of C^{14} in the Earth's atmosphere as being due to the action of cosmic rays is generally accepted. The neutrons of the secondary component of cosmic rays' form radiocarbon according to reaction $N^{14}(n,p)C^{14}$ *. Like ordinary carbon, the radiocarbon oxidizes and mixes with the normal carbon dioxide in the atmosphere. Plants absorb carbon dioxide from the atmosphere, while animals feed on plants. Therefore, the vegetable and animal world contain radiocarbon. Atmospheric radiocarbon penetrates also into the oceans in the form of dissolved carbonate and bicarbonate. Moreover, the ratio between radiocarbon and ordinary carbon concentrations is approximately 10^{-12} (in a contemporary organic substance C^{12} - 98,9%, C^{13} - 1,1%, C^{14} - 10^{-10}%). If a

* Radiocarbon is formed also in reactions $O^{16}(n, He^3)C^{14}$, $O^{17}(n, \alpha)C^{14}$, $N^{15}(n,d)C^{14}$, $C^{13}(n,\gamma)C^{14}$. However, it is easy to demonstrate that the contribution of these reactions to the rate of C^{14} formation is negligibly small.

specimen drops out of the exchange cycle as a result of the death of animals or plants, the decay of C^{14} is not compensated at the expense of CO_2 absorption from the atmosphere. Therefore, radiocarbon concentration decreases with the half-life of C^{14}, which is $T_{1/2} \simeq 5730$ years [2].

Therefore, an experimental determination of the number of undecomposed atoms in a material containing carbon makes it possible to calculate the time elapsed since the moment of carbon exchange cessation. The radiocarbon dating method, which brought to its author Libby the Nobel Prize, is based on this fact. The radiocarbon dating method is based on three postulations:

1. The intensity of cosmic rays and, consequently, the rate of radiocarbon formation in the Earth's atmosphere is constant during several half-lives of C^{14}.

2. The radiocarbon content in various reservoirs is constant during an equal time.

3. The rate of C^{14} transition from the atmosphere into other reservoirs, and into oceans in particular, is also constant.

By measuring radiocarbon content in samples whose age is known Libby and Anderson [3] have shown that during several half-lives the specific activity of C^{14} is constant with precision of up to several percent. Thereby, the reliability of the dating method was confirmed and numerous investigations were started.

With the development of C^{14} measurement technique the presence of radiocarbon concentration was detected in the Earth's atmosphere. As a result of combustion of billions of tons of organic mineral fuels (oil, gas, coal), an important role was played for the last 100 years by the intake into the atmosphere of ancient carbon devoid of C^{14}. Estimates have shown that from 1860 to 1954, the "old carbon" added in the atmosphere constituted $\sim$ 13% of its total carbon content. If the mixing between the various reservoirs were instantaneous, the C^{14} concentration in the atmosphere would vary by only 0.13% and the dilution effect (Suess effect) would not have been detected. Suess has demonstrated [4] that the C^{14} concentration on account of the combustion effect has actually decreased by 2%. On the basis of these data Ferguson [5] determined the mean sojourn time of carbon dioxide molecules in the atmosphere. It proved to be less than 7 years.

De Vries [6] drew attention to the short-period variations of C^{14} concentration in specimens of known age around 1700. He assumed that these fluctuations are connected with climatic changes in the world at large, and compared them with the advances and retreats of glaciers from the 17th century to the present time.

Analysis of yearly wood layers carried out on tree samples accurately dated for the last 1300 years has shown substantial fluctuations in the C^{14} content [7]. These fluctuations reflect the real changes of C^{14} content in the atmospheric carbonic acid.* the variations of cosmic radiation could be one of the most probable causes of these changes. The cosmic radiation variations are due to cyclic changes in solar activity and they possibly accompany such relatively rare phenomena as the bursts of supernovae etc.,

In this connection we have outlined in [1] the importance of comparing C^{14} content in the age-rings of both live and archeologically-dated trees with historically known astronomical phenomena or with the data of modern observations enabling us to determine the date of some catastrophic event in the past.

When article [1] was sent for publication, the experimental data on C^{14} concentration in samples of known age were scarce. Later appeared the works [8-11], dealing with investigations on radiocarbon content in a large number of specimens of known age.

Such an intense interest in determining the C^{14} concentration in dendrochronologically dated specimens had convinced us even more of the necessecity of investigating the problem of the possible role of radiocarbon in astrophysical studies.

The total quantity of C^{14} in all the reservoirs determined by the equilibrium between C^{14} decay and formation processes, constitutes $\sim$ 60 tons. The main mass of C^{14} (90%) is contained in oceans (mainly in inorganic compounds). The remaining quantity is contained in the atmospheric carbon dioxide, in the Earth's biosphere and in the humus. The total amount of C^{14} in the Earth's atmosphere is $\sim$ 700 kg ($3 \cdot 10^{28}$ atoms). Exchange of carbon exists between the reservoirs and, on the average, a dynamic equilibrium takes place. If, for some cause, the C^{14} content in one of the reservoirs, for instance in the atmosphere, undergoes a change, then, after a certain lapse of time the equilibrium is again re-established. What is essential is that the volume of the atmospheric reservoir as compared to the total volume is very small . Consequently, even relatively major changes in the C^{14} content of the atmosphere result in small variations of the total C^{14} content in the entirety of the reservoirs. In this connection it is very important to know the dynamics of radiocarbon exchange between the reservoirs.

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* The yearly process of carbon assimilation in trees is connected with the yearly formations of a new wood layer. In the following year this layer is virtually excluded from carbon-hydrogen exchange. Therefore, the C^{14} content of an annual layer corresponds to the concentration in C^{14} of the atmosphere during the year of this layer's formation.

To solve this problem the respective balance equations are usually composed, taking into consideration two reservoirs, namely the atmosphere and the ocean* [10,12]:

$$\dot{X}_1(t) = Q(t) - (\lambda + \lambda_1)X_1 + \lambda_2 X_2 \ ,$$
$$\dot{X}_2(t) = \lambda_1 X_1 - (\lambda + \lambda_2)X_2 \qquad (1)$$

where index 1 relates to the atmosphere, and index 2 to the ocean:

X is the quantity of C^{14} in g.cm^{-2}; Q is the rate of C^{14} formation in g.cm^{-2} year^{-1}; $\lambda = \frac{1}{\tau}$ year^{-1} is the C^{14} decay constant;

λ_1 is the probability of C^{14} transition from atmosphere to ocean in one time unit, and λ_2 is the probability of C^{14} transition from ocean to atmosphere in one time unit.

Lt us examine two cases: a) the quantity of radiocarbon in the atmosphere changes instantaneously by the quantity ΔX_1 g.cm^{-2}. $\cdot (\Delta Q(t) = \Delta X_1 \delta(t))$. This case corresponds to explosive processes, such as the explosion of a nuclear bomb or the outburst of a supernova; b) $\Delta Q(t) = |\Delta Q| e^{i\omega t}$. This case corresponds to cyclic processes. As an example we may cite the solar activity. Let us introduce the following symbols: A_1 and A_2 which are respectively the C^{12} g.cm^{-2} for the atmosphere and the ocean; $R_1 = \frac{X_1}{A_2}$ and $R_2 = \frac{X_2}{A_2}$ are the concentrations of C^{14} relative to C^{12} respectively in the atmosphere and in the ocean; $\lambda^* = \lambda + \lambda_1 + \lambda_2$, Q_0 is the rate of C^{14} formation in g.cm^{-2} year^{-1} averaged in time. Taking into account these symbols the solution of equations 1 for the case "a" may be represented in the form [13,14]:

$$\Delta R_1 = \frac{\Delta X_1}{A_1(1+\nu)} \left(e^{-\lambda t} + \nu e^{-\lambda^* t} \right)$$
$$\Delta R_2 = \frac{\Delta X_1}{A_1(1+\nu)} \left(e^{-\lambda t} - e^{-\lambda^* t} \right) \ , \qquad (2)$$

where $\nu = \frac{A_2}{A_1} = \frac{\lambda_1}{\lambda_2} = \frac{T_2}{T_1}$; T_2 is the mean time of C^{14} transition from ocean to atmosphere, and T_1 is the same quantity for the reverse process.

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* Obviously, all reservoirs should be taken into consideration for a more accurate solution of the problem. However, we shall abstain from so doing for two reasons: first, not all the characteristic times of mixing between reservoirs are known; secondly, taking into account all reservoirs brings about only an insignificantly slight change in the overall results, virtually not affecting the basic conclusions.

Generally speaking, the presence in the oceans of mixing layers (intense mixing goes on down to depths of $\sim$ 75 m) makes it necessary to investigate three reservoirs, namely the atmosphere, the ocean surface layers and the ocean depth layers. However, formulas (2) can be used provided one considers ocean surface layers either as a part of the atmospheric or ocean reservoir. In the first case, ν is found to be equal to 30, in the second case to 60 (the amounts of C^{14} in the atmosphere and in the surface layers are approximately equal). At the present time the exact value of T_1 is unknown. According to the existing data, T_1 finds itself in an interval between 6 and 30 years [12,13].

$$\frac{\Delta R_1}{R_2} = F_1 \frac{|\Delta Q|}{Q_0}, \qquad \frac{\Delta R_2}{R_2} = F_2 \frac{|\Delta Q|}{Q_0}, \tag{3}$$

where

$$F_1 = \sqrt{\frac{1 + \left[\frac{(\nu+1)\tau T^*}{\tau + \nu T^*}\right]^2 \omega^2}{(1 + \tau^2 \omega^2)(1 + T^{*2} \omega^2)}}$$

$$F_2 = \frac{1}{\sqrt{(1 + \tau^2\omega^2)(1 + T^{*2} \omega^2)}}$$

Formulas (2) and (3) will be used later on when the problem of variation of radiocarbon concentration in the Earth's atmosphere due to a supernova outburst and cyclic solar activity is investigated.

III. SUPERNOVAE AND RADIOCARBON

140 residues of supernovae are known at the present time. Among them the following supernovae exist in our Galaxy: Cassiopeia A (1700), Kepler (1604), Tycho Brage (1572)and the supernova in the Crab nebula (1504). Depending upon their characteristics, supernovae belong to type I or type II*. The basic characteristics of supernovae based on the data of works [15-20] are presented in table I.

The type I supernovae burst at an equal frequency in both the elliptic and the spiral galaxies, concentrating in the regions of galactic nuclei, while the supernovae of type II burst mainly in the galactic spiral arms.

A special characteristic feature of type I supernovae is the

* Zwikke counts five supernova types [15].

TABLE I

Characteristics of Supernovae

Type	Photographic stellar value in the luminosity maximum (on the average)	Light energy (erg)	Supernovae mass ($M_\odot$)	Mass of ejected shells ($M_\odot$)	Shell Velocity (km/sec)	Shell Kinetic energy (erg)	Presence of hydrogen in shells	Relation to stellar population
I	$-19{,}04 \pm 0{,}23$	$4 \cdot 10^{49}$	1,2 – 2	0,1 - 1	1000 – 2000	$10^{48} - 4 \cdot 10^{49}$	-	Old Stars
II	$-17{,}70 \pm 0{,}34$	$2 \cdot 10^{49}$	10	1 - 10	5000 – 10000	$2{,}5 \cdot 10^{50} - 10^{52}$	+	Young Stars

complete similarity of luminosity time dependence curves. Following a rapid rise of brightness and a smooth maximum there occurs during 20-30 days a drop by 2-3 stellar magnitude (Fig.1) [20]. Then the luminosity decreases exponentially with a half-life of 40-70 days. For the type II supernovae the shapes of the spectra differ noticeably from one another. What they have in common is a relatively slow drop at the beginning, as compared with type I supernovae.*

The hypothesis according to which the energy release of type-I supernovae is due to the spontaneous fission of such nuclei as Cf^{254}($T_{1/2}$ = 55 days) is based on the presence of the exponential drop [21]. At the same time it is assumed that the Cf^{254} nucleus is formed at the expense of the "r" process. Formation of $\sim 10^{30}$g of Cf^{254} is necessary to explain the observed luminosity of supernovae.

As the exponential luminosity drop is characterised for each supernova by a quite specific half-life , it became necessary to assume [21,22] that the luminosity of each supernova is due to the spontaneous fission of a specific isotope. This last assumption is obviously the weakest point of "the Cf^{254} hypothesis".

Colgate [20,23,24] considers that when a degenerated neutron nucleus is formed in the star, there occurs a reflection to the outside of the substance dropping forward the center of the star. As a result there appears a shock wave. As it drifts away from the center, the wave intensifies, since the density of the matter decreases. As a result, the velocity at stellar surface becomes parabolic and part of the matter is ejected in the interstellar space. The energy then liberated may reach $\sim 10^{52}$ergs. In the Colgate model relativistic particles can be generated in the outermost layers of the star.

Finzi [25] has recently demonstrated the possibility of supernova energy release being due to vibrational oscillations. In this case the vibrational energy may attain $\sim 10^{52}$ ergs [26].

Even a short study** shows a lack of unanimity on the problem of supernovae outburst mechanism mainly due to the scarcity of experimental data.

To understand the physical nature of phenomena occurring during supernovae outbursts, it is essential to know whether the supernovae emit γ-quanta and, if so, what are their intensity and their energy spectrum.

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* Precisely because of this and despite the difference in luminosity, the light energy emitted by both type I and Type II supernovae is almost identical.

** For a detailed study see [15].

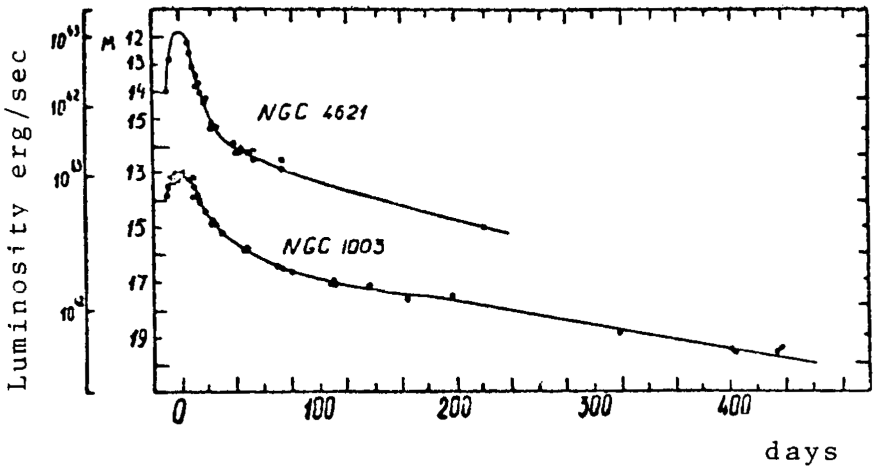

Fig.1.

Time dependence of the luminosity of the supernovae of type 1.

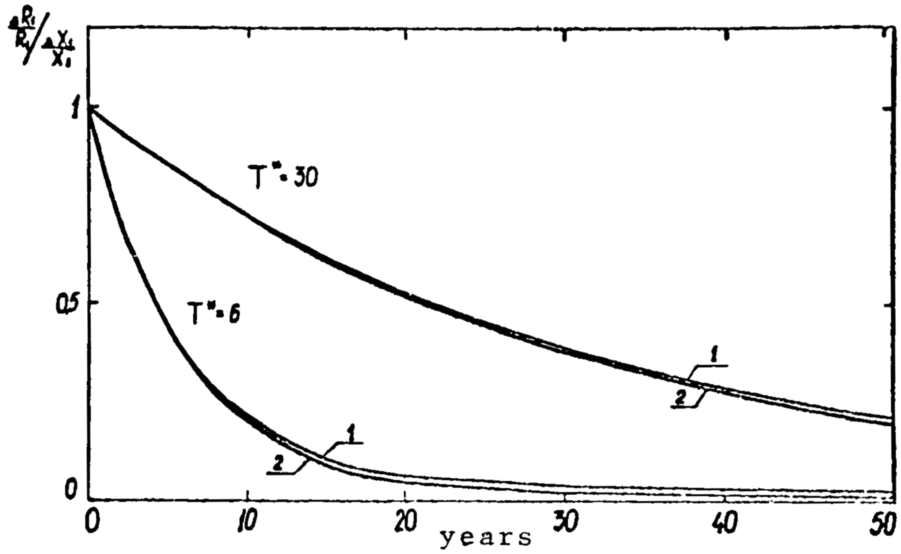

Fig.2.

Variation of C^{14} concentration in the Earth's atmosphere following a supernovae outburst:

$I - \nu = 30, \quad 2 - \nu = 60.$

It is shown in [1] that a supernova outburst in our galaxy must be accompanied by a noticeable change of radiocarbon concentration in the Earth's atmosphere if the supernova γ-luminosity is only slightly lower than its optical luminosity. Arguments in favor of a high γ-luminosity of supernovae are contained in the recent works of Clayton and Craddok [27] and Gould and Burbidge [28].

If during supernova outbursts there are formed by the "r" process a large number of heavy nuclei, including radioactive nuclei, γ-quanta have to be emitted. The sensitivity of modern γ-detectors does not permit the registration of γ-quanta caused at the present time by supernovae outburst in other galaxies. Therefore, there naturally arises the question: what is the γ-radioactivity of supernovae fragments in our galaxy which is due to nuclei which as yet have not completly desintegrated. Basing their arguments on "the Cf^{254} hypothesis", Clayton and Craddok [27] have investigated the problem of γ-radioactivity of the Crab nebula. They have shown that out of the total power of Crab nebula radioactive nuclei, equal to $\sim 1,2 \cdot 10^{36}$ erg/sec, only 1% correspond to the share of γ-quanta. The main part of the released energy is the kinetic energy of α-particles and fission fragments. The strongest γ-line belonging to Cf^{249} has an energy of 390 kev. The flux of such γ-quanta on Earth is $\sim 5 \cdot 10^{-5} \gamma\ cm^{-2} sec^{-1}$ [7]. The registration of this radiation is hindered by the presence of X-ray background of the Crab nebula. This background is synchrotronous and has a continuous spectrum. The 390 kev line can be detected by means of equipment with high angular and energy characteristics. The setting up of experiments for the registration of γ-quanta with energy of 390 kev is of major importance for a positive result would constitute a direct corroboration of the hypothesis according to which the formation of heavy nuclei during supernovae outbursts takes place at the expense of the r-process.

Gould and Burbidge [28] suggest the two following mechanisms of γ-quanta formation during supernovae outbursts:

1. Nuclear γ-rays emitted in the process of nucleon fusion.

2. γ-rays emitted at the expense of relativistic particles' interaction with the magnetic field and the matter within the expanding shell of the star.

According to Gould and Burbidge, the flux of nuclear γ-rays ($E \sim 1$ Mev) at a distance of 1 k parsec from a supernova (1 k parsec is the distance between Crab nebula and Earth), during outburst is $\sim 10^{4}\ \gamma\ cm^{-2} sec^{-1}$, while at a distance of M parsec (the distance between Earth and extragalactic supernovae) it is $10^{-4}\ \gamma\ cm^{-2} sec^{-1}$.

Currently, the presence is established of a large quantity of relativistic electrons in supernova fragments. It is also shown that, apparently, there takes place at present a generation of relativistic electrons, i.e., 900 years after the outburst of the supernova. Moreover, it has been established that the electrons are primary and not secondary electrons*. It is natural to assume that the electron injector is a former supernova and its relatively small surrounding region [15]. It is equally natural to assume that such an acceleration mechanism occured during the active stage of the supernova outburst. The relativistic protons accelerated at the time of the outburst during their interaction with the stellar shell matter must form pions. The decay of charged pions yields neutrinos, electrons and positrons, while that of Π° mesons yields γ-quanta. As a result, the formation of a large quantity of γ-quanta with energy of 50-100 Mev may be expected. Besides due to the reverse Compton effect, the interaction of electrons and positrons with thermal photons will also yield γ-quanta.

As Gould and Burbidge have noted very correctly [28], their considerations on the generation mechanism of γ-quanta are to a very high degree speculative, fact which stresses again the extremely unclear situation now prevailing in the question of supernova outburst mechanism. At the same time they underline the exceptional importance of the problem of the possible γ-quanta generation during the active stage of supernovae outbursts.

As a matter of fact, the absence of high-energy γ-quanta would be evidence against the generation of a large quantity of relativistic protons, and vice versa.

It is suggested in [1] that the mechanism of radiocarbon formation in the Earth's atmosphere is due to the action of γ-quanta which possibly accompany supernovae outbursts. During the interaction with the nuclei of the Earth's atmosphere, γ-radiation can form neutrons on the basis of reactions: (γ,n), $(\gamma, 2n)$, (γ, pn), $(\gamma, \alpha n)$ etc., Moreover, the secondary particles (p,d) can also form neutrons.

Making use of the value of the cross-sections of corresponding photonuclear reactions [30-33], we obtain for the probability of neutron formation by γ-quanta with energy of 25 Mev a value $\sim$ 5% and $\sim$ 2% for $E_\gamma \simeq 50$ Mev.

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* Had the electrons been of a secondary nature, positrons and γ-quanta would have been formed together with them. The experiments of Chudakov et al [29] have shown that the γ-quanta flux from the Crab nebula with $E > 5\cdot10^{-12}$ ev is lower than $5\cdot10^{-11}$ photons $cm^{-2}sec^{-1}$, i.e. it is lower by a factor of 1000 than was expected under the assumption of the secondary origin of the relatavistic electrons in the Crab nebula.

Libby [34] had shown as early as in 1946, that in their interaction with nitrogen, neutrons generated in the atmosphere are being absorbed, forming radiocarbon on the basis of the reaction (n, p).

The variations in radiocarbon concentration in the Earth's atmosphere following the explosion of supernovae in our Galaxy are presented in Table II for three values of the total γ-radiation energy, namely 10^{48} ergs, 10^{50}ergs and 10^{52} ergs.

The available data on the 1054, 1572, 1604 and 1700 supernovae bear witness to the fact that the total energy of the relativistic electrons generated by a star attains a magnitude of 10^{48} - 10^{49} ergs per outburst [35,36]. It is considered [36] that the total energy of all cosmic rays is by two orders higher than the relativistic electron energy, i.e. that it amounts to 10^{50}-10^{51} ergs per outburst. On the other hand, the upper limit of the total energy of cosmic rays is of the order of the total energy of the explosion reaching 10^{51} - 10^{52} ergs and even 10^{53} - 10^{54} ergs [15, 19,37,38]. If the formation of γ-quanta is due to the interaction of relativistic protons with the matter of the supernova shell, the total energy of the γ-component must be of the same order as the energy of cosmic radiation (or, in any case, only slightly lower).

To evaluate the variation of radiocarbon concentration in the Earth's atmosphere it is necessary to know also, besides the γ-component energy, the distance between Earth and supernova. Unfortunately, the available data differ sometimes by one order of magnitude. For instance, according to [15,16,36,39], the distance between the Earth and the Tycho-Brage supernova would be 360 parsec (1500-1700)parsec, 2400 parsec and 3300 parsec, respectively. The distance to the Kepler supernova varies within 1000 parsec [36] and 9900 parsec [39]. Depending upon the shape of the Crab nebula, the distance to it could be 1100 parsec (a flattened shape, with two equal axes and a third smaller axis) or 1700 parsec (an elongated shape, with two equal axes and a third longer axis. As regards Cassiopeia A, all authors agree that the distance to it is 3400 parsec.

The variations of radiocarbon concentration in the Earth's atmosphere presented in Table II reflect this lack of accuracy in determining distances.

At the present time, the accuracy of the registration of radiocarbon concentrations in the age-rings of trees attains 0.3% and there is a possibility of increasing it to (0.1 - 0.05) %.

A study of the data contained in Table II shows that when the energy of the γ-component is not below 10^{49} erg it is possible to detect experimentally the variation of the C^{14} content in the Earth's atmosphere due to a supernova outburst.

T A B L E II

Variations of C^{14} concentration in the Atmosphere

SOURCE	Rad ation energy Mev	Variation of Radiocarbon Concentration in Atmosphere / % /		
		Total Energy γ - components /erg/		
		10^{48}	10^{50}	10^{52}
Kepler supernovae (1604)	25	$5\cdot10^{-4} - 5\cdot10^{-2}$	$5\cdot10^{-2} - 5$	5 - 500
	50	$10^{-4} - 10^{-2}$	$10^{-2} - 1$	1 - 100
Tycho Brage supernovae (1572)	25	$10^{-2} - 4\cdot10^{-1}$	1 - 40	$10^{2} - 4\cdot10^{3}$
	50	$2\cdot10^{-3} - 8\cdot10^{-2}$	$2\cdot10^{-1} - 8$	20 ÷ 8000
Cassiopeia A (1700)	25	$5\cdot10^{-3}$	$5:10^{-1}$	50
	50	10^{-3}	10^{-1}	10
Crab Nebulae (1054)	25	$/2 - 4/\cdot10^{-2}$	2 - 4	200 - 400
	50	$/4 - 8/\cdot10^{-3}$	$/4 \div 8/\cdot10^{-1}$	40 ÷ 80

As already pointed out above, there are no reliable estimates of the γ-component energy. Only one thing is clear. According to up-to-date concepts, the emissions of γ-quanta by supernovae in an amount sufficient for the detection of outbursts by radiocarbon is not excluded. In these circumstances, we are of the opinion that it is necessary to determine experimentally the C^{14} content in the Earth's atmosphere with a precision of not less than (0.3 - 0.1)% for the years corresponding to the outbursts of the already known supernovae. If the effect proves to be positive, it will become possible to evalu te the energy of the γ-component during a supernova outburst. Then it will become, to a certain degree, possible to choose one of the hypotheses among those now existing with regard to the mechanism of supernovae outbursts. Moreover it will then become possible to investigate experimentally the undetected outburst.

It is also of considerable interest to establish the exact date of the Cassiopeia A. At present time it is considered that it flared around 1700.

Fig.2 shows the time dependence of C^{14} content variation in the Earth's atmosphere calculated on the basis of formula 2 for two values

$$\frac{1}{\lambda^*} = T^* \simeq T_1 - 6_\wedge, 30_\wedge \text{ and } \nu - 30, 60.$$

Let us note, that actually the front of concentration increase will not be as sharp. First, because in the supernovae the outburst process is of a finite life-luminosity relation (fig.1.) and, secondly, because of the delay in the mixing of C^{14} in the Earth's atmosphere. Apparently, the first cause changes only slightly the shape of the curves shown in Fig.2 since the main mass of supernova energy is emitted in less than one year. As to the mixing time there are at the present time no accurate data. It was mentioned [40] that the mixing time in the stratosphere is 5 years, and in the troposphere 1 - 2 years.

If one succeeds in detecting supernovae outbursts experimentally and in determining the time dependence of the variation of C^{14} concentration in the atmosphere, it will become possible to determine the characteristic times of C^{14} mixing in the Earth's atmosphere and of its transition in other reservoirs.

IV. SOLAR ACTIVITY AND RADIOCARBON

It was reliably ascertained that the intensity of primary cosmic rays reaching the Earth depends on solar conditions. During the 11-year cycle of solar activity the total intensity of cosmic rays undergoes considerable changes. These variations are connected with the motion conditions of cosmic rays in the interplanetary space and are mainly related to low-energy particles. Thus, for example, the intensity of protons with energy of 100 Mev varies from solar activity minimum in (1953, 1954 and 1965) to a maximum (1958) by a factor of 4, while for protons with energy E = 2,5 Bev the variation does not exceed 40%.

With the variation in the flux of primary cosmic rays, the rate of neutron formation changes, and, consequently, the rate of C^{14} formation in the Earth's atmosphere.

In [41] the problem of variation in the rate of radiocarbon formation from the solar activity minimum (1953-1954) to its maximum (1957-1958) is investigated in detail.

The basic results of work [41] are presented in Table III.

If one assumes a linear connection between the number of sunspots and the formation rate (q) of C^{14}, we may obtain the following expression:

$$q = 2{,}61 - \frac{0{,}53(S - 9{,}1)}{178{,}4},$$

where S is the mean annual number of sunspots (1953-1954 S = 9,1; 1957-1958 S = 187.5). Then, for the last 111 years we have 2.50 ± 0.50 atoms $cm^{-2}sec^{-1}$ as the mean rate of C^{14} formation [41]. It should be noted that the estimates did not take into consideration the C^{14} formation under the action of neutrons generated as a result of interaction of solar flare protons with atmospheric nuclei. In reality the rate of C^{14} formation averaged for many periods of solar activity will exceed 2.5 $cm^{-2}sec^{-1}$.*

On the other hand the rate of C^{14} decay in the same units is 1.8 ± 0.2 [12] and 1.9 ± 0.2 [42].

This conveys the impression that in the last 100 years the rate of C^{14} formation was higher than the rate of decay, so that radiocarbon concentration in the Earth's atmosphere must have increased.

It should be noted that the reliability of the calculated

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* Let us mention that at the solar activity maximum the rate of C^{14} formation drops because of the decrease in the intensity of primary cosmic rays and rises on account of nuclear reactions due to the action of solar flare protons. According to Stuiver [43], the effect of flare protons must be weak.

values of C^{14} formation (Table III) is low (error $\sim$ 20%) which means that the error overlaps the difference between the quantities 2.6 and 2.08. However, this circumstance cannot eliminate the experimentally determined variations in the neurtron flux and, consequently, in the rate of C^{14} formation from solar activity

T A B L E III

Velocity Formation C^{14} atoms sm^{-2} sec^{-1}

Geomagnetic Latitude	Velocity Formation C^{14}	
	1953 - 1954	1957 - 1958
0	0,98	0,93
10	1,01	0,96
20	1,22	1,15
30	1,83	1,63
40	3,02	2,45
50	4,52	3,44
60	5,26	3,79
70-90	5,38	3,79
mean latitude	2,61	2,08

minimum to its maximum. The aforementioned figures should be considered as tentative and requiring accurate experimental checking.

Therefore, it can be concluded that there are indications on variations by 20% of the rate of C^{14} formation from solar activity minimum to its maximum, as well as of a monotonic increase by an identical quantity for a period of $\sim$ 100 years.

Formula 3 makes it possible to determine the amplitude of variation in the radiocarbon content of the Earth's atmosphere. Fig. 3 shows the dependence of function F_1 on the period of variation in the C^{14} formation rate. It shows that the attenuation factor is $\sim 10^{-2}$ for a period of 10 years, and $\sim 10^{-1}$ for 100 years In other words, if for an 11-year cycle of solar activity the rate of C^{14} formation varies by 20%, the amplitude of variation in the concentration is 0.2%. For a period of 100 years the variation in the concentration will constitute $\sim$ 2%.

Thus, we reach the conclusion that in order to study past conditions of solar activity it is necessary to measure radiocarbon concentrations in dendrochronologically dated samples with great precision (not less than 0.2 - 1 %).

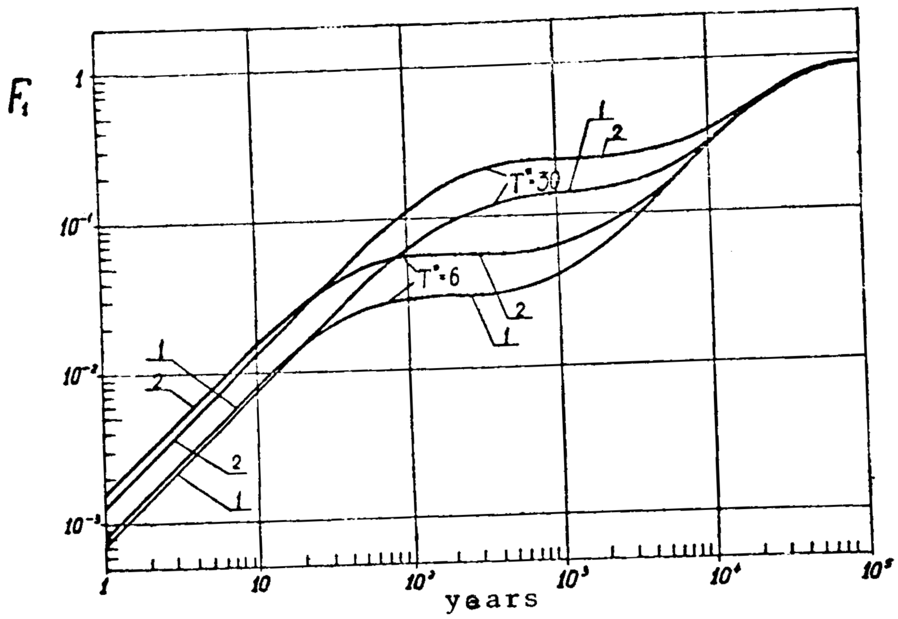

Fig.3.

Dependence of function F_1

on the period of C^{14}

formation rate:

I - ν = 30, 2 - ν = 60.

V. EXPERIMENTAL POSSIBILITIES

A complete cycle of experimental investigations includes the following stages:

1. Preparation of the required quantities of dencrochronologically dated samples.
2. Determination in the latter of radiocarbon content.
3. Determination of radiocarbon content in the Earth's atmosphere on the basis of its experimentally determined concentration in samples of known age.

We will briefly examine all these stages in sequence.

1. Dendrochronology is a method of dating arboreal plants on the basis of their annual rings. Usually, an annual ring is formed during one vegetative season. The width of the annual ring depends on many factors*, namely - the age of the plant, the location of the layer in the stem, the periodicity and strength of fertility, the meteorological conditions, the shading of the trees, forest fires etc.,[44]. The enormous quantity of various factors, whose specific influence on the width of the ring is unknown, means that comparison of the width of rings from two different trees for the same year would be meaningless. Substantial conclusions can be reached only by comparing the rings of the same tree for different years. As the influence of a number of factors is identical in considerable areas, the dynamics of ring growth is identical for various trees growing at the same time and not far from each other. This circumstance is important in the relative dating of different trees. When one succeeds in ascertaining the absolute age of some tree it becomes possible to develop an absolute dendrochronological scale. Such a scale makes it possible to determine the age of the wood with an accuracy of up to 1 year. The first absolute dendrochronological scale for the years 698 to 1929 was developed by A. Douglas (1935) for the south-western regions of the United States [45].

In the USSR the first absolute scale was developed by B.A. Kolchin on Novgorod materials (wood pavements, drainage systems, lower log rows of buildings). The length of the entire scale is 578 years, from 884 to 1462 [44]. Kolchin's absolute scale was intended for pines growing in productive types of forests. Obviously, the age of all kinds of wood cannot be determined on the basis of this scale [45].

Therefore, to determine the exact date of growth of any ring it is necessary to have an absolute dendroscale for a given type of tree and a given place of grwoth.

With trees growing at the present time the matter is relatively simple. However, here also one meets with complications because it happens that in some years there are growths of several rings, while in other years there is no ring at all. In this case it is absolutely necessary to develop a dendroscale based on measurements of the ring width for numerous trees of a given type and in a given region.

As regards radiocarbon measurements there arises the additional difficulty of obtaining a large quantity of wood from one

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* Leonardo da Vinci had remarked as early as in the 15th centuary that the succession of narrow and wide annual rings in the trees corresponds to the succession of humid and dry years.

annual ring. For instance, in order to determine radiocarbon content with an accuracy of up to (0.2 - 0.3)% several hundred grams of wood are required for the scintillation method of C^{14} measurements. On the other hand, in order to measure the content with an accuracy of (0.02 - 0.03)% the required quantity of wood would be 100 times greater, running into tens of kilograms.

Thus it should be borne in mind that serious difficulties lie ahead in the realization of our concepts on the role of radiocarbon in astrophysical investigations. The situation is aggravated by the fact that there exists in the USSR only one laboratory for dendrochronology located at the Institute of Archeology of the USSR Academy of Science. We deem it absolutely necessary to intensify sharply the investigations on dendrochronology not only because the precisely dated rings are indispensable, but also because this field is by itself of great scientific and practical interest.

2. Determination of C^{14} Concentration in the Samples

Radiocarbon concentration in the samples is determined by means of proportional and scintillation counters. Presently installations have been worked out which make it possible to determine C^{14} concentrations with an accuracy of up to 0.3%. The accuracy of the determination is limited by the background and stability of the installation, and the quantity of radiocarbon. The latter depends in its turn both on the age of the sample and the quantity of wood. The age can be determined up to 50,000 years. A further increase in the limit age is substantially hindered by the necessity of disposing of a large quantity of wood. Indeed, with calculation efficienty of 100% and measurement time of 10^6 sec, 1 g of modern wood is required to attain an accuracy of 1 %. One kg is required for measuring 50,000 years of age, and as much as one ton for measuring 100,000 years. Moreover, the limited volume of the detector necessitates isotopic enrichment of C^{14} relative to C^{12} and C^{13}. All other conditions being identical and with a sufficient quantity of wood, increase in age limit requires a thousandfold enrichment for every 50,000 years. Therefore, even if one had hundreds of tons of ancient wood, limitations in age determination would occur because of the difficulty of isotopic enrichment*.

We should like to say a few words on the accuracy of dating. At the present time the radiocarbon method of dating has an accuracy of $\sim$ 1%. This is due not only to statistics. Even if the statistical error and the background of the counter system were

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* When working with ancient specimens, other difficulties, arise necessarily, the danger of contamination by modern carbon in particular.

zero, it is doubtful that it would be possible to measure with better accuracy than 1%. As a matter of fact radiocarbon concentration in the Earth's atmosphere varies in time with an amplitude fluctuation having reached in the past several percent. On the other hand, when determining the age it is assumed that during the tree growth epoch the radiocarbon content was the same as now.

After measuring with a high accuracy the time dependence of C^{14} concentrations, it will become possible, in principle, to measure the age of the sample with an accuracy of up to 1 year, not on the basis of the average activity of the sample, but on the basis of the annual variation chart. As regards the measurements of C^{14} content in dendrochronologically dated specimens, besides the difficulty of obtaining large quantities of wood, substantial difficulties arise with regard to the stability of the experimental equipment. For an accuracy of 0.01% the total number of registered β-particles of C^{14} must be 10^8, which for a velocity of $10^2 sec^{-1}$* requires a measurement time of $\sim$ 10 days. During this time the stability of count effectiveness must be assured with a precision of not less than 0.01%. In the existing installations β-particle measurements are carried out in a power window set by two treshold voltages. At a high counting rate, the background of the installation does not constitute any peril in the region of high energies. Therefore, the upper threshold can be fixed above the β-spectrum boundary therby reducint the requirements for its stability. Matters are worse with respect to the lower threshold which depends on noise pulses. Here, it becomes necessary to use a special system for forced stabilization.

3. Determination of Radiocarbon Content in the Earth's Atmosphere

Let us examine in brief the existing difficulties in determining radiocarbon content in the Earth's atmosphere on the basis of the experimental values of C^{14} concentrations in the age-rings of trees.

First of all it should be ascertained whether the migration of radiocarbon from one ring to another, does exist or not. Special experiments dealing with investigations of C^{14} content in rings of live trees prior and following the period of nuclear bomb tests, were carried out in a number of laboratories. It is well known that the C^{14} content due to nuclear bombs, increased more than twofold in the atmosphere. Measurements have shown with a precision to

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* Such a velosity is not easy to attain.

fractions of one percent that no migration from external to internal layers had taken place.

It was established that plants assimilate C^{12} better than the heavier C^{13} and the still heavier C^{14}. On the other hand, the exchange mechanism between atmospheric carbon dioxide and oceanic carbonate brings about a large C^{14} concentration in the carbonates. Quantitative results have been obtained by measuring C^{13} concentrations on mass spectrometers taking into consideration that the enrichment factor for C^{14} is twice as high as that for C^{13}. As a result it was found that the C^{14} concentration is by 1.2% higher in carbonates than in the atmosphere, while in the plants it is by 3.7% lower. However, the main fact is that these values depend on local conditions of the tree growth with the resulting necessity of measuring the C^{12}/C^{13} ratio for each specimen, especially in cases involving an accuracy of more than 1%.

As regards the dependence of radiocarbon concentration on the latitude of the locality, recent investigations [46] have demonstrated with a precision to several tenths of one percent that radiocarbon concentration in a ring does not depend on latitude.

VII. INVESTIGATION OF EXISTING EXPERIMENTAL DATA

Works [8-11, 47, 48] published in the last two years present the experimental values of radiocarbon concentration in samples of known age for a wide range of time which goes from our days to 1000 years B.C. (Figs. 4-8). The data presented in the figures show that for the last 3000 years radiocarbon concentration in the Earth's atmosphere has not remained constant. There are clearly expressed minima and maxima. Maxima are clearly expressed around 1500 and 1700, and minimum around 1600. They were already detected in earlier works [6,7]. The maxima around 700 and 380 and only slightly indicated. (Figs. 4,6).

With recession into the past, the radiocarbon concentration monotonically decreases reaching a minimum around the beginning of our era. Than it increases up to the year 1000 B.C.

Therefore, among the variations of the C^{14} concentration in the atmosphere, it is apparently possible to distinguish changes with characteristic times of 2000 and 200 years.

Tables showing the time dependence of Wolf numbers from 649 B.C. to our days are presented in [49]. These dependences are based on an analysis of the available data on Wolf number variation in time and on informations concerning earthquakes, aurorae borealis and other natural phenomena. In our present work we are not in a

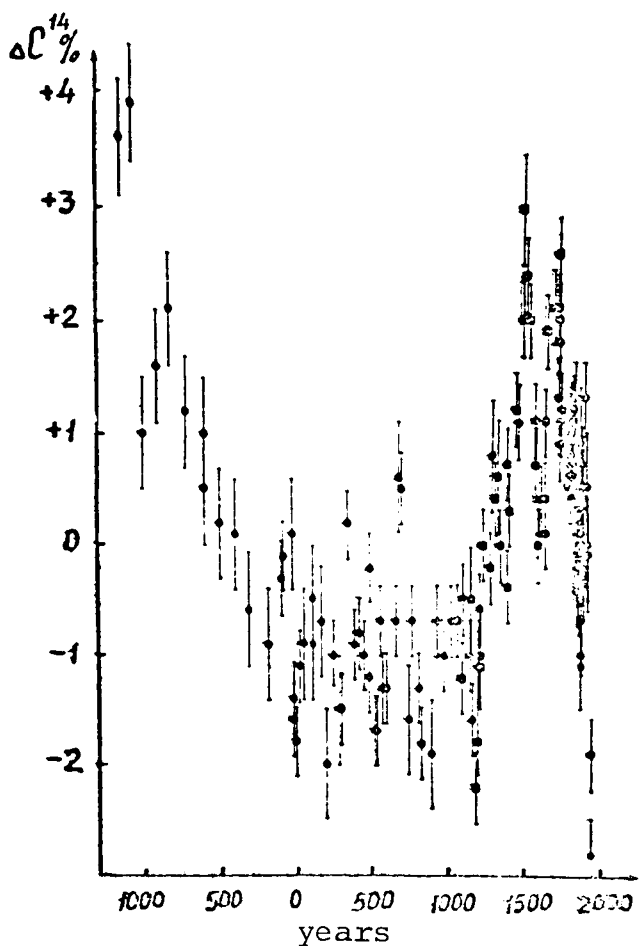

Fig.4

Variations of radiocarbon concentration in the Earth's atmosphere during the last 3000 years according to the data of Suess [8].

position to discuss the reliability of Wolf number values presented in [49].

We shall only note that systematic investigations of sunspots were carried out only beginning with the middle of the 18th century and, therefore, the Wolf number values for earlier periods were calculated under specific assumptions requiring an experimental

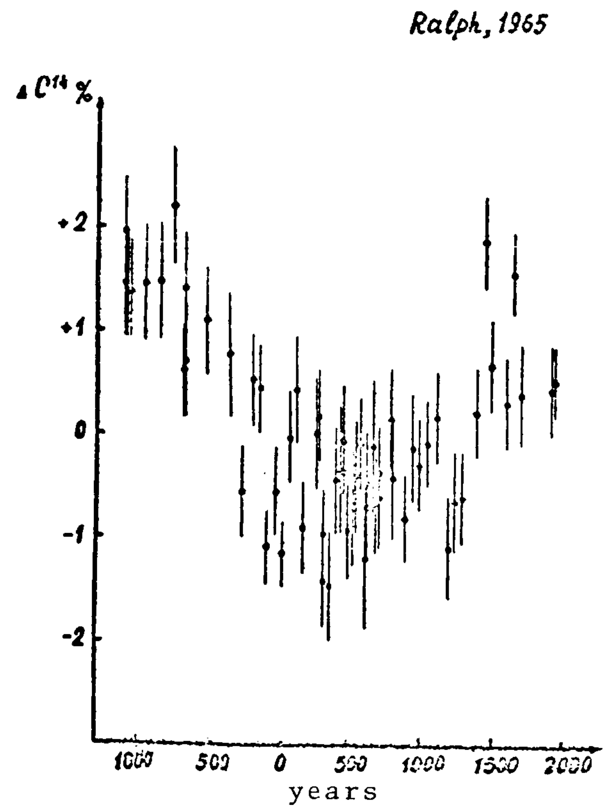

Fig. 5.

Variations of radiocarbon concentration in the Earth's atmosphere during the last 3000 years according to data in [9]

verification, Fig.9 shows the time dependence of the Wolf numbers for the last 1000 years according to [49].

Comparison of Fig.9 and Figs.7,8 shows that the maxima of radiocarbon content in the Earth's atmosphere in 1500 and 1700 coincides with the minima of Wolf number time dependence. This coincidence leads us to suppose that the 200-year variations in the Earth's atmosphere are due to solar activity. Then, in accordance with the date of Fig.3, the variation in C^{14} content by 2% may be due to the variation in the rate of C^{14} formation if it is $\sim$ 40%. This variation in C^{14} formation rate can be obtained if

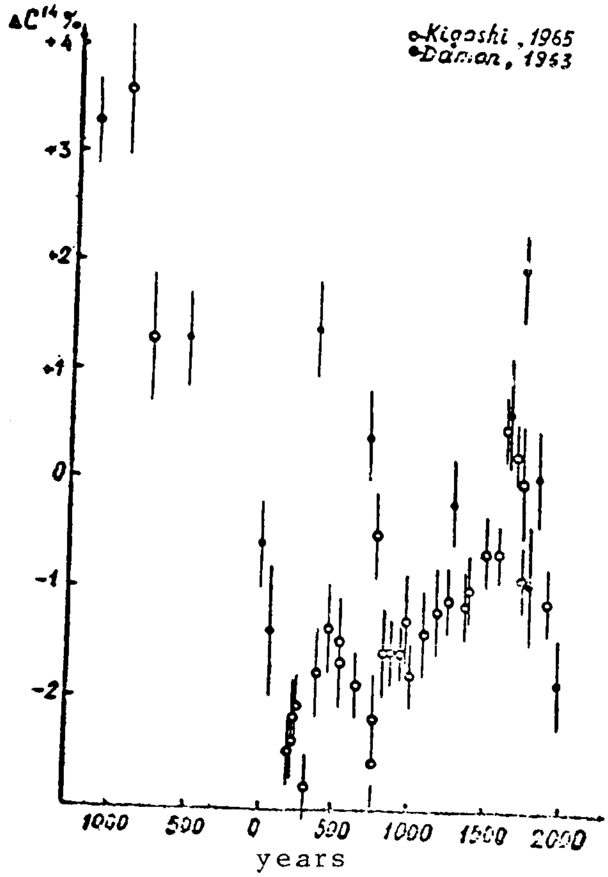

Fig.6.

Variations of C^{14} concentration in the Earth's atmosphere during the last 3000 years according to data in [10] (light circles) and [11] (dark circles).

one considers the connection between the Wolf number and the rate of radiocarbon formation as linear.

Thus, we arrive at the conclusion that the experimental data on C^{14} variation in the Earth's atmosphere for the last 400-500 years are not in contradiction with the assumption that there

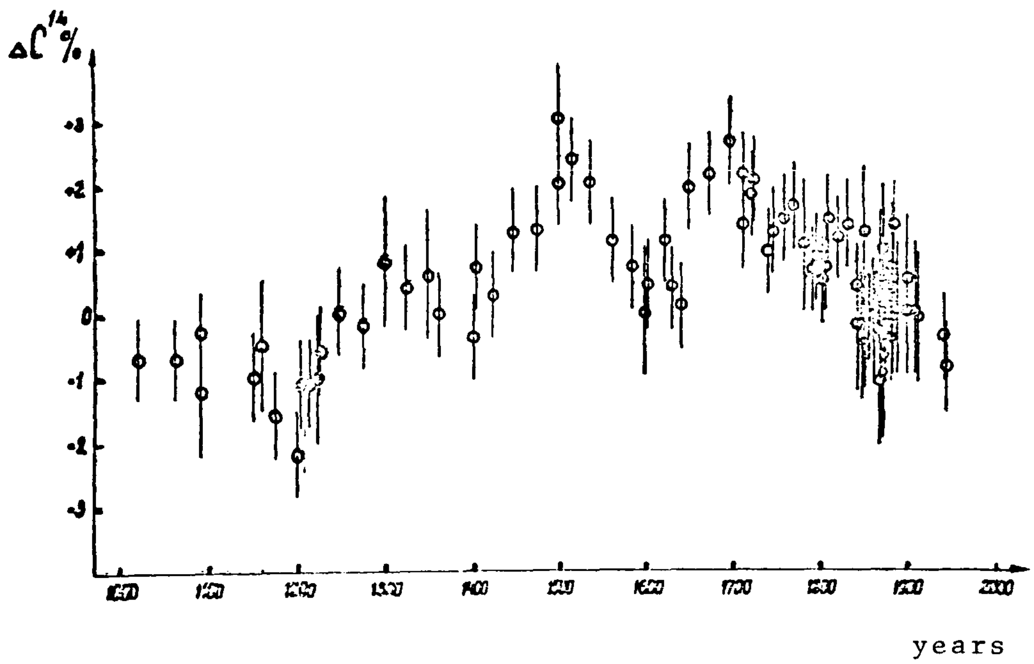

Fig.7.

Variations of C^{14} concentration in the Earth's atmosphere during the last 1000 years according to data in [8].

exists a correlation between Wolf numbers and radiocarbon concentration. Naturally, some points remain unclear. In particular, why is the 200-year cycle clearly expressed only in the last 400-500 years? What is clear is that if the 200-year wave existed in earlier periods its amplitude did not exceed 1% (Fig.4-8). This means that if the 200-year solar activity cycle does actually exist, its characteristics vary in time. More detailed and precise measurements of radiocarbon content in the Earth's atmosphere may possibly reveal the 200-year wave and, what is most important, define its characteristics in the past.

The available experimental data do not permit to formulate any somewhat substantiated conclusion on the supposed 78-year solar activity cycle [49].

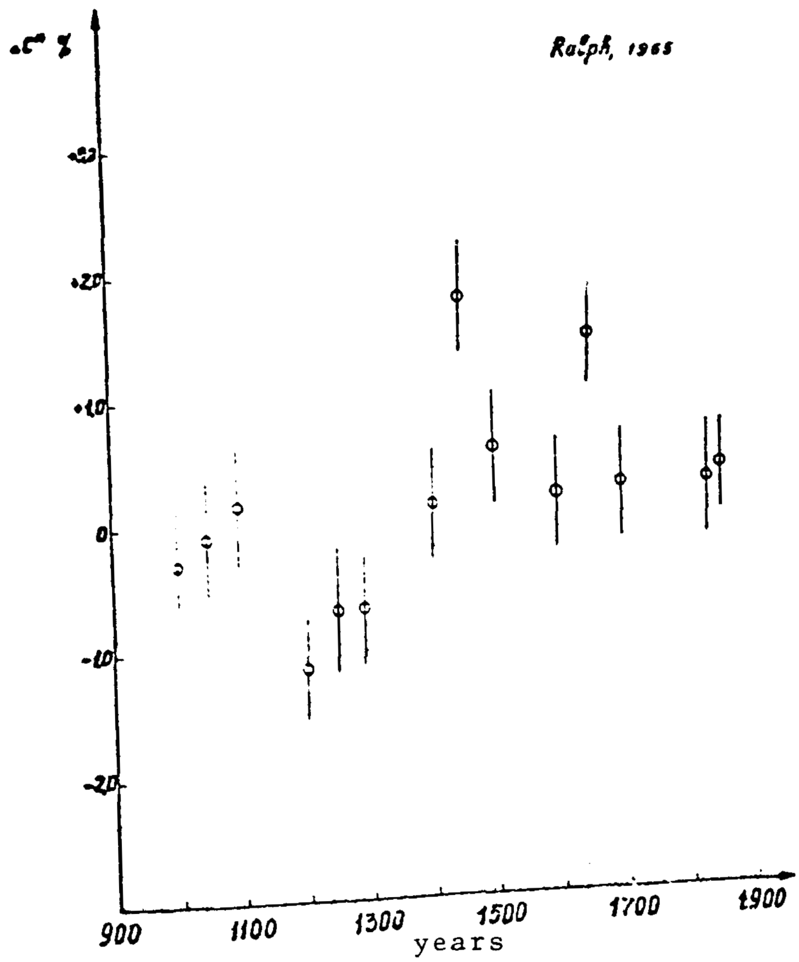

Fig. 8.

Variations of C^{14} concentration

in the Earth's atmosphere during the last

1000 years according to data in [9].

What conclusions could be drawn regarding the effect of supernova outbursts? We shall note outright that although there are no detailed investigations for the years close to supernova outbursts. Nevertheless some conlcusions can be made on the basis of the available data. Let us examine all the outburst in sequence.

Supernova in the Crab Nebula (1054)

The C^{14} content was experimentally determined in samples for the following years:
1023±3, 1067±7, 1096 4, [8]; 1003±11, 1052±10, 1100±8 [9]; 956±10, 1056±10, 1136±10 [10]; 1009±25, 1109±25 [7].
Indicated are not the errors in the determination of samples' age, but the duration of the time interval for which the rings were taken.

The only conclusion that can be derived when comparing data in Figs. (4-8) and Table II consists in that, apparently, the total energy of γ-radiation of the supernova in the Crab nebula was below 10^{52} ergs.

The Tycho Brage Supernova (1572)

The C^{14} concentration was determined in samples for the years:
1537±2, 1563±1, 1582±2, [8]; 1450±10, 1505±13, 1597±5 [9]; 1516±10, 1596±10, 1656±10 [10]; 1509±25, 1579±25, 1609±25 [7].
In this case it can only be concluded as cautiously as for the Crab nebula, that the total energy of the γ-component probably does not exceed 10^{52} ergs.

The Kepler Supernova (1604)

The C^{14} content is known in specimens for the following years:
1582+2, 1597±2, 1605±5, 1622±2 [8]; 1597±5, 1646±4, [9]; 1596±10, 1657±10 [10]; 1559±25, 1609±25, 1659±25 [7].
Comparison of data of Table II and Figs. 4-8 makes it possible to evaluate the upper limit for the total energy of γ-component. It proves to be 10^{52} ergs.

The Cassiopeia A Supernova (∿1700)

The C^{14} content was experimentally determined for the years:
1695±5, 1710±10, 1712±2 [8]; 1646±4, 1697±5, 1829±13 [9]; 1676±10, 1696±10, 1650±10 [10]; 1659±25, 1709±25, 1759±25 [7].
As already mentioned, all the authors had detected a maximum of radiocarbon content in the Earth's atmosphere around 1700. This maximum may be due to the cyclic activity of the Sun. There are no detailed annual investigation for the years surrounding 1700 either. Therefore, we can only note that during the outburst of Cassiopeia A supernova the total energy of the γ-component could hardly have exceeded 10^{52} ergs.

Thus, we arrive at the conclusion that at the present time there are no detailed investigations for the years corresponding to the outbursts of supernovae. It is therefore impossible to arrive at a conclusion regarding the presence or absence of a correlation between supernova outbursts and the C^{14} concentration in the Earth's atmosphere. It can only be asserted that neither theoretical considerations nor experimental data exclude the possibility of such a correlation.

As already mentioned, with a recession into the past the C^{14} concentration in the Earth's atmosphere decreases monotonically, reaches its minimum around the beginning of our era,

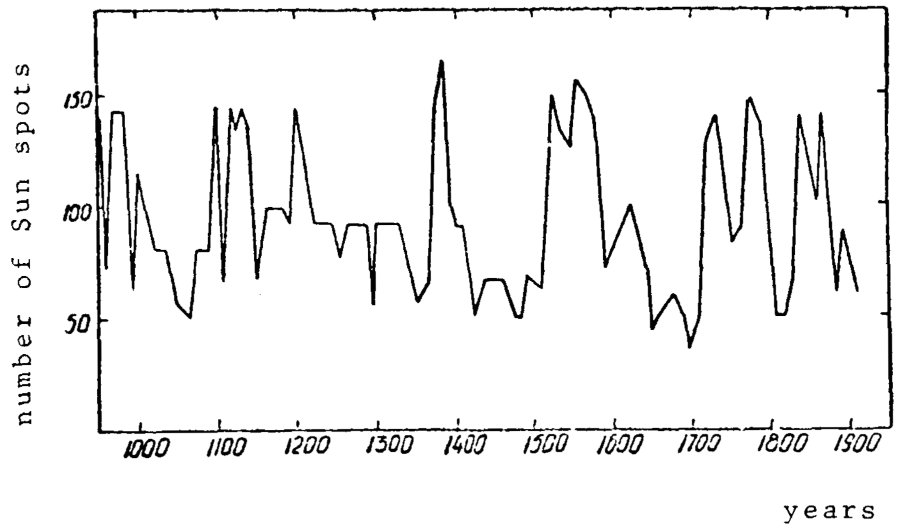

Fig. 9.

Time dependence of the number of sunspots [49].

and then increases up to the year 1000 B.C. The cause of this change is up to now unclear. This variation in the past may be due to variations in time of the Earth's magnetic field. As is well known, the intensity of cosmic rays incident upon the Earth's atmosphere decreases with the increase of the Earth's magnetic field. According to available experimental data on the thermoremanent magnetization of calcined clay [50] it follows that the intensity of the Earth's magnetic field had increased up to the beginning of our era, reached the magnitude of 1.4 H_0 (H_0 being the field intensity at the present time) and then began to decrease In other words the maximum of the Earth's magnetic field coincides with the minimum of the C^{14} content in the Earth's atmosphere. This circumstance allowed the authors of [10] to reach the conclusion that the 2000-years wave as a function of the time dependence of the C^{14} concentration, is due to variations of the Earth's magnetic field.

Besides the aforementioned causes, the variations of radiocarbon content in the Earth's atmosphere may be also due to variations in the rate of mixing between the various reservoirs caused by climatic changes in the past, vulcanic activity and so forth.

Moreover, according to another hypothesis variations in the C^{14} concentration take place with the entry of antibodies in the Earth's atmosphere. The antibody nature of the Tungusska meteorite is cited as an example [47]. In connection with the great interest aroused by the antibody problem, it seems advisable to dwell somewhat more in detail on the results of the investigations of C^{14} content around 1908, which was the year of the fall of the Tungusska meteorite.

The Tunguska meteorite exploded in the atmosphere at an altitude of 5-10 km on June 30, 1908 at 12 hr 17 min a.m.UT (about 7 a.m. local time) in Siberia in the region of the Stony Tunguska river. According to various estimates, the energy of the explosion reached 10^{23} - 10^{24} ergs. We shall not dwell on the various hypotheses which were advanced concerning the nature of the Tunguska meteorite. We will only examine the hypothesis concerning its antibody nature. Let us assume that the Tunguska catastrophe was caused by the entry of an antimeteor in the Earth's atmosphere. This caused the formation of neutrons at the expense of annihilation. On the basis of nitrogen reaction (n,p) these neutrons yielded C^{14}. Analysis shows that 2-3 neutrons, and not 8 ± 4 as indicated by Cowan, Atluri and Libby [47], are formed for each anhilated antinucleon. Then, with total energy of the Tunguska body equal to 10^{24} ergs the total number of the formed C^{14} nuclei should be $(6-10) \cdot 10^{26}$, i.e. the variation in C^{14} content would be 2-3%. If we took for the minimum estimate of the Tunguska body the energy of 10^{23} ergs, the increase would be by (0.2 - 0.3)%. Cowan, Libby and Atluri have determined with precision of up to 3% the C^{14} concentration in the annual layers of wood (oak and fir from the State of Arizona) from 1870 to 1936. Their results are presented in Fig.10 and show that, as compared with 1908 and 1909, an increase in C^{14} activity was detected in 1909. As this increase lies within the limits of measurement errors, it would be, to say the least, venturesome to conclude that we have here a confirmation of the antibody hypothesis.

Investigations for determining the C^{14} content in the annual rings of a tree from the region where the Tunguska body exploded were carried out at the Institute in the name of Vernadskiy [48]. The results of these investigations are shown in the same Fig. as those of [47]. A 140-year larch fallen in the fall of 1961 was the object of the investigation. The vegetative season of this type of tree lasts from the end of May to the middle of September so that an increase in C^{14} should be expected in the 1908 ring. As is shown in the obtained data (Fig.10), the content in 1908 rings is higher than in 1909 and 1910. This would seem to confirm a connection between the Tunguska catastrophe and the C^{14} content in the Earth's atmosphere. However, as in [47], the measurement error overlaps the difference between the concentrations for 1908,

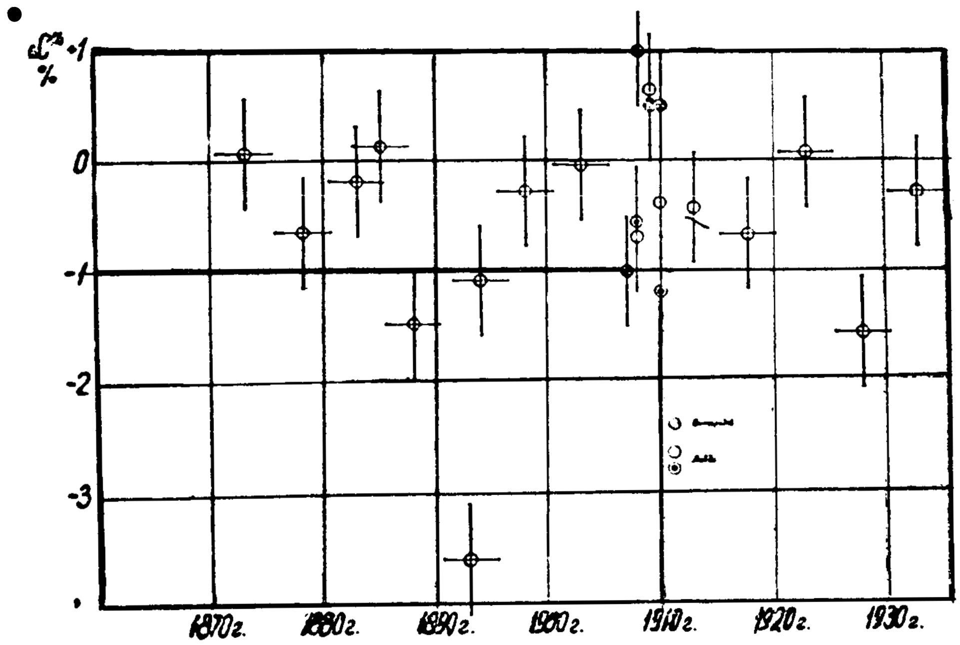

Fig.10.

C^{14} concentration in dendrochronologically

dated tree rings:

o - according to data in [48]

o ⊙ - according to data in [47]

1909 and 1910. Therefore, in our opinion, the only conclusion that can be made on the basis of data obtained in [47, 48] is that the experimental data on C^{14} do not exclude the possibility that the Tunguska body is of antibody nature.

There is still another serious objection against the antibody nature of the Tunguska body consisting in that the probability of an antibody penetrating the atmosphere to such a great depth is extremely slight.

Venkatavaradan [51] considers that variations in the C^{14} content in Earth's atmosphere near the year 1908 is due to the cyclic activity of the Sun. One of the minima of solar activity occurred in 1909 and, in principle, an increase in C^{14} could correspond to it. However, let us note that comparison of the time dependence of sunspot numbers (Fig.11) with the data of Fig.10 shows

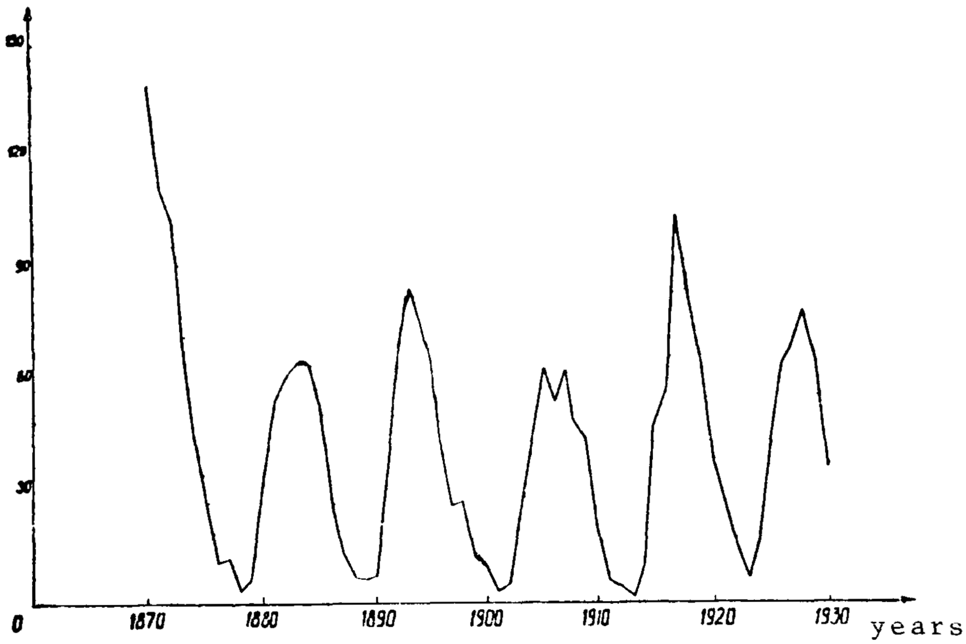

Fig. 11.

Time dependence of the number of sunspots [49].

that the minima and maxima of Fig.10 do not necessarily correspond to those of Fig.11. In any case, the problem of the connection between C^{14} content and the Tunguska catastrophe cannot be considered as solved and requires further investigations.

VII. BRIEF CONCLUSIONS

1. The problem of the possibility of studying various astrophysical phenomena (cyclic activity of the Sun, outbursts of supernovae etc) by determining the radiocarbon content in dendrochronologically dated specimens is investigated.

2. It is shown that outbursts of supernovae can be attended by an increase of C^{14} content in the Earth's atmosphere by a magni-

tude accessible to registration, provided the γ-quanta emitted during the outbursts, have a total energy not much lower than that of cosmic rays.

If the correlation between supernova outbursts and radiocarbon concentration in the Earth's atmosphere is detected experimentally, it will become possible to obtain information on outburst characteristics and, in particular, to determine the total energy of the γ-component.

Knowledge of the time dependence of C^{14} concentration in the Earth's atmosphere will make it possible to determine the characteristic times of mixing in various reservoirs. Moreover, it will be possible to determine the dates of up to now undetected outbursts, as well as their characteristics.

3. A detailed investigation of the C^{14} content in the Earth's atmosphere for a long time interval in the past will make it possible to determine the conditions of solar activity in various past years, as well as the regularities occurring in the solar activity,

4. To realize the comprehensive "Astrophysical phenomena and radiocarbon" program, it is necessary:

a) to develop a dendrochronological method of determining the age of wood in a wide range of time from our days to several thousand years before our era and more.

b) to develop methods of determining C^{14} concentration with precision of (0.3 - 0.1)%. Special attention should be paid to the stability of the experimental equipment and the reproducibility of the results.

To improve the basic parameters of the existing methods (accuracy, stability, reproducibility) of C^{14} registration, namely the proportional and scintillation counters, it is necessary to develop, besides the obvious methods (reduction of background, increase of detector volume, use of stabilization systems), also methods for C^{14} enrichment relative to C^{12} and C^{13}. Thus, for instance, an enrichment by a factor of 100, all other conditions being equal, results in a tenfold improvement of statistical accuracy. On the other hand, with an identical statistical accuracy, working with an enriched carbon requires less time and, correspondingly, yields results of better stability and reproducibility.

In a number of cases, especially when working with ancient samples, the quantity of carbon is limited. In these cases, the mass-specrometric method of determining the quantity of C^{14} atoms could be more expedient. The sensitivity of the mass-spectrometric method can attain 10^{10} of C^{14} atoms (gain by a factor of 30 as compared with the existing methods). The development of high-sensitivity mass spectrometers and the enrichment of C^{14} relative to C^{12} and C^{13} will make it possible to increase the age limit accessible to measurements.

c) To develop a quantitative mechanism for the connection between astrophysical phenomena and the radiocarbon content in the Earth's atmosphere.

V. We realize the serious difficulties confronting the realization of a complete program of investigations on the problem "Astrophysical phenomena and radiocarbon". Nevertheless, we deem it necessary to carry out these investigations because, besides the abovementioned advantages, they will make it possible:

1) to improve distinctly the level of dendrochronological studies in the USSR;
2) to improve the basic parameters (accuracy, reproducibility) of the existing methods of C^{14} atoms count; this will permit to carry out by the radiocarbon method the traditional age measurements of samples with high precision and reliability and in a shorter time.

VI. Knowledge of annual C^{14} variations in the Earth's atmosphere will make it possible to date archeological wood with, in principle, an accuracy of 1 year, not on the basis of its mean activity, but on the basis of the annual variatons chart.

* * * THE END * * *

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